arrays consume large amounts of input power (10KW or more) and the waste heat to be radiated may exceed 5kW.

Because these antennas typically have a diameter of the order of 3 metres, in normal circumstances, the surface area is sufficient to allow dissipation of the excess thermal energy and the maintenance of normal operating temperatures. However, for a direct radiating antenna oriented towards the Earth, the solar input may be of the order of about 1kW per square metre for several hours per day. For such antennas, dissipation of such solar input is not possible using conventional OSRs because the reflective metal layer, typically silver or aluminium, is opaque at microwave frequencies.

It is an object of the invention to provide a film material that provides thermal control in spacecraft applications and meets microwave transmission requirements. It is further object of the present invention to provide a thermal film material for space craft applications that does not require a metal layer to achieve reflection.

From a first aspect, the present invention resides in a metal free thermal control film for use in managing thermal properties of spacecraft antennae comprising a multi-layer interference filter adapted to exhibit preselected high absorbency and emissive characteristics in the far infrared wavelength range 2.5μm to 50μm, low absorbency characteristics in the solar spectrum range 200-2500nm and high transmissive characteristics in the microwave frequency spectrum 1 to 30GHz.

The combination of high reflectivity to solar radiation, low absorptivity across the microwave spectrum and a high emissivity in the far infra-red exhibited by the film constructed according to the present invention provides the desired thermo-optical properties for a thermal control radiator surface that can be used on surfaces such as the active face of a communications or radar antenna, without causing disruption of RF signals.

The thermal control film, being metal free, exhibits high transparency to the microwave frequencies used by communications and radar. In addition, the absence of metal is advantageous in that the film will not be susceptible to corrosion or electromagnetic interference that may affect operation of spacecraft equipment.

Figure 4 illustrates the desired reflectance spectrum of a thermal film constructed in accordance with an embodiment of the present invention;

Figure 5 is a simplified representation of a spacecraft-mounted active transmit antenna incorporating a thermal control film according to the present invention fitted to its active surface.

Recent technological achievements have led to the relatively inexpensive construction of thin-film interference filters featuring major improvements in wavelength selection and transmission performance. The basic concepts employed in thin film interference filters are:

(i) the amplitude of reflected light at the boundary between two media is given by (1-r) / (1+ r) where r is the ratio of the refractive indices at the boundary;

(ii) there is a phase shift of 180 degrees when reflectance takes place in a medium of lower refractive index than the adjoining medium, and zero phase shift if the medium has higher refractive index than the adjoining one; and

(iii) if light is split into two components by reflection at the upper and lower surfaces of a thin film, then the beams recombine in such a way that the resultant amplitude will be the difference of amplitudes of the two components if the relative phase shift is 180 degrees (destructive interference), or the sum of the amplitudes if the relative phase shift is either zero or a multiple of 360 degrees (constructive interference).

Figure 2 illustrates the basic type of thin film structure used in interference filters and consists of a stack of alternating high and low index dielectric films, all of one quarter wavelength in thickness. Light reflected within the high index layers will not suffer any phase shift due to reflection, whereas light reflected within the low index layers will undergo a 180 degree phase shift as a result of reflection. Since all of the layers are one quarter wavelength thickness (90 degree phase thickness), it can be seen that the different components of the incident light produced by reflection at the incident boundaries are all in phase at the front surface of the film. These beams combine constructively and the intensity of the beam is very high in comparison to the incident beam. The effective reflectance of the film can be made very high for a particular wavelength by increasing the number of alternating layers in the stack. The range of wavelengths for which the reflectance remains high

301 (trade name for fused natural quartz product having low hydroxyl content), crystal quartz and sapphire. For OSRs, a borosilicate optical glass such as BK7, is typically chosen due to its excellent optical properties, stability in a space environment and its cost.

Multi-layer optical thin film interference filters can now be manufactured with all-polymer components. Typically, polymeric thin film filters are made by co-extruding all layers simultaneously with or without a substrate and can be formed as free-standing film stacks having anywhere from 10 to 1000 layers with controlled thickness distribution. For added toughness, outer skin layers may be included in the co-extruded film stacks and may consist of one of the polymers in the optical layers in the film stack or can be a different material. The choice of polymers used is based on a number of criteria, including refractive index and melt characteristics. The final optical properties of the mirror (i.e., variations in refractive index from one later to the next) can be precisely controlled by alternate stretching and cooling of the multi-layer polymer material) which is equivalent to the insertion of new layers in the needle optimisation technique described above.

Such thermal films can be shaped to the form of the surface to which it is to be joined by thermoforming, which uses a combination of heat and pressure to conform the film to the shape of a pre-made mould. The mould is first shaped to that of the surface to which the film is to be laminated. Once thermoformed, common optical adhesives or other fixing methods can then be employed to join the film to the surface. Cold shaping of polymer multi-layer film is also possible in applications where fabrication of a pre-made mould is not feasible.

The thermal control film according to a preferred embodiment of the present invention comprises a polymeric multi-layer structure comprising a set of interference filters designed and optimised to exhibit the desired optical characteristics as is illustrated in Figures 3 and 4. The film is required to have low absorbency of solar radiation, which includes part of the UV spectrum (200-400nm), the visible spectrum (4000-750nm) and the near infrared spectrum (750-2500nm). The film must also exhibit high absorbency and emissivity in the far infrared wavelength range (2.5μm to 50μm), that corresponds to the spectrum of heat generated by the high frequency circuits associated with the

T/R modules of the antenna array. A further essential criterion is that the film exhibit a high transparency to the microwave frequencies, typically 1 to 30GHz, used by communications and radar observation. Since the film is to be designed for use in space, the materials used should not only be capable of withstanding the temperature variations involved but also be able to maintain the optical characteristics required in such an extreme environment. Also since the bandwidths of the rejection bands are very high, the ratio of refractive indices between the materials used in the film should be as high as possible.

The thermal film used in the preferred embodiment comprises a multi-layer polymeric film such as the Radiant Mirror Film products from 3M™. The 3M Radiant Mirror Film VM2002 is an experimental or developmental material which is made available for evaluation, testing or experimental purposes and comprises a multi-layer polymeric film with an outer protective layer of polyethylenenaphthalate to prevent degradation of the final optical properties through abrasion, moisture ingress or other environmental factors. The film is metal free and so will exhibit a high transparency to the microwave frequencies used by communications and radar equipment. In addition, the absence of metal is advantageous in that the film will not be susceptible to corrosion or electromagnetic interference that may affect operation of the antenna. The film material is thermally stable with a maximum continuous use temperature up to 125°C, and typically exhibits high reflectance over a (400-415) nm to (775-1020nm) bandwidth with an angle of incidence range of 0 to 80 . The film transmits wavelengths in the near infrared spectrum above 775-1020nm and exhibits low absorbency above 400nm (i.e., the visible and infrared spectrum). An additional coating can be applied to the film so as to achieve the desired lower absorbency in UV spectrum if desired.

Although in the above embodiment, the film is based upon a commercially available material which is then adapted so as to achieve the desired optical characteristics, it should be understood that a customised material can be manufactured to the precise specifications required. Such customised films can be obtained from specialist suppliers such as 3M™ and numerous others. As described earlier, the angle of incidence of radiation is an important factor in such a multi-layer film. For north-south radiating surfaces of

Claims:

1. A metal free thermal control film for use in managing thermal properties of a spacecraft antenna comprising a multi-layer interference filter adapted to exhibit preselected high absorbency and emissive characteristics in the far infrared wavelength range 2.5µm to 50µm, low absorbency characteristics in the solar spectrum range 200-2500nm and high transmissive characteristics in the microwave frequency spectrum 1 to 30GHz.

2. A thermal control film according to claim 1, where the film covers the active face of an antenna carried by the spacecraft.

3. A thermal control film according to claim 1 or 2, wherein the film is in the form of a flexible sheet.

4. A thermal control film according to claim 1 or 2 wherein the film is in the form of a liquid coating to be applied to a surface of the spacecraft.

5. A thermal control film according to any preceding claim wherein the multi-layer interference filter is a polymeric structure.

6. A thermal control film according to any preceding claim, wherein the multi-layer interference filter comprises one or more layers of any combination of SiO_2, SiO_xN_y, and Si_3N_4.

7. A thermal control film according to claim 6, wherein the film is in the form of a plurality of tiles.

8. A thermal control film according to any preceding claim, wherein the thickness of the film is less than 200microns.

9. A thermal control film according to any preceding claim, wherein the thickness of the film is in the range of 50 to150microns.

10. An antenna comprising a thermal control film according to any preceding claim, covering the active face thereof.